Measurement of the Sea Spray Droplet Size Distributions at High Winds

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Award Number: N00014-02-1-0673
Award Number: N00014-02-1-0662 (DURIP)
http://www.apl.washington.edu

LONG-TERM GOALS

Our long-term goals are to develop phase-Doppler anemometry for measuring size-segregated droplet concentrations and fluxes at high wind speeds in the atmospheric boundary layer (ABL).

OBJECTIVES

Our objectives for FY 2002 were to evaluate commercially available phase-Doppler anemometers for suitability in measuring spray droplets in the ABL, to purchase a compatible system based on the results of the evaluation, begin the engineering required to mount the instrument on a research aircraft, and design an experiment to test the instrument in a wind-wave tunnel.

APPROACH

At high wind speeds, droplets are injected upwards into the ABL. Bursting bubbles generate film and jet drops, with radii that vary from a few tenths of a micrometer to a few tens of micrometers for film drops [*Resch and Afeti*, 1992; *Spiel*, 1998] with jet drop radii as large as 150 μm [*Rossodivita and Andreussi*, 1999]. Droplets are also produced by spume, or the shearing off of the crest of waves. Spume drops are typically larger than film and jet drops, with radii from a few tens of micrometers up to several hundred micrometers [*Andreas et al.*, 1995; *Wu*, 1973]. Measurement of droplets concentrations in the ABL under hurricane-force winds therefore requires accurate measurement of particle concentrations over several orders of magnitude in particle size.

The total number density of droplets in the ABL may be quite large, and the particle sizing technique must be capable of sizing droplets in flows with total number densities (i.e., number or particles of all sizes) on the order of 10^4 particles per cm^3. However, the concentration of the larger particles ($r \approx 100$ μm) may also be quite low (on the order of 10^{-4} particles per cm^3). Thus, the chosen instrument combination must also have considerable sensitivity and dynamic range. Aircraft deployment requires that the instrument also be capable of measuring particle size in flows with velocities as large as several hundred meters per second. Concomitant with these requirements are that the sampling volume be small and sub-sampling of the air stream for the particle measurements not be required. This last requirement is important because droplets should be measured in an undisturbed airstream so

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2002**	2. REPORT TYPE	3. DATES COVERED **00-00-2002 to 00-00-2002**
4. TITLE AND SUBTITLE **Measurement of the Sea Spray Droplet Size Distributions at High Winds**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Applied Physics Laboratory, University of Washington,,1013 NE 40th Street,,Seattle,,WA, 98105**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR’S ACRONYM(S)
		11. SPONSOR/MONITOR’S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		

14. ABSTRACT

Our long-term goals are to develop phase-Doppler anemometry for measuring size-segregated droplet concentrations and fluxes at high wind speeds in the atmospheric boundary layer (ABL).

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a REPORT **unclassified**	b ABSTRACT **unclassified**	c THIS PAGE **unclassified**	**Same as Report (SAR)**	**5**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

that their size distribution will be unaffected by changes in relative humidity or deposition losses during sampling. One type of commercially available instrument that can be adapted to this task is a phase-Doppler anemometer (PDA).

In similarity with a laser-Doppler velocimeter, a PDA measures the velocity of a moving particle by determining the Doppler shift in frequency of scattered light. However, a PDA also measures the particle size [*Asher and Farley*, 1995]. It uses the principle that when the same scattering event is viewed at two different locations, there is a phase difference, $\Delta\Phi$, between the two signals due to the difference in optical path to the detectors. Assuming the scattering geometry remains constant and the scattering particles are spherical, $\Delta\Phi$ is a function of particle radius, r, and the geometry of the scattering system [*Bauckhage et al.*, 1988]. Therefore, for a given scattering mechanism (e.g., first-order refraction) with a known system geometry (e.g., scattering angle, location of detectors) the relationship between $\Delta\Phi$ and r has a closed-form analytical expression [*Bauckhage et al.*, 1988] and measuring $\Delta\Phi$ allows calculation of r. It has been demonstrated that PDA systems accurately measure the number-size distributions of spherical particles in the submicron and supermicron size ranges [*Asher and Farley*, 1995; *Göbel et al.*, 1998; *Rossodivita and Andreussi*, 1999].

The total size range spanned by film, jet, and spume drops is well within the detection range of a PDA. In fact, phase-Doppler anemometry has been used in the laboratory to study both submicron-sized aerosol populations [*Göbel et al.*, 1998] and jet drops ejected from bursting bubbles [*Rossodivita and Andreussi*, 1999]. These particle sizes span the size range of spray droplets. Commercially available PDA instruments also have very fast sampling rates, allowing them to make measurements in flows up to several hundred meters per second with particle densities as high as 5×10^5 particles per cm^3 (e.g., TSI Phase-Doppler Particle Analyzer Technical Reference, www.tsi.com).

We are proposing to conduct aircraft-based measurements with the PDA in collaboration with the main CBLAST hurricane research experiments in 2003 and 2004. We will coordinate our aircraft installations through Dr. Peter Black of the NOAA Atlantic Oceanographic and Meteorological Laboratory. The PDA will provide size-segregated droplet concentrations as a function of aircraft altitude. The PDA data will be compared to droplet concentrations measured from the same aircraft by Dr. Chris Fairall using a cloud/precipitation droplet probe (CPDP). Data from both instruments can be used in a droplet boundary layer model such as formulated by *Kepert et al.* [1999] to determine the droplet source function. Details on this approach can be found in *Kepert et al.* [1999] or *Pattison and Belcher* [1999]. Once the source function is accurately known, it will be possible to model the contribution of droplets to surface exchange processes.

We also plan to conduct joint experiments with Dr. Fairall in a wind/wave tunnel in January of 2003 to intercompare the CPDP and PDA instruments. At present, these experiments will be conducted with Profs. Michael Banner and William Pierson at the University of New South Wales (UNSW) in Sydney, Australia. Dr. Fairall has verified that the wind-wave tunnel at UNSW can attain high enough wind speeds so that spray drop production will be easily measured using both instruments.

WORK COMPLETED

We have evaulated the performance of the two commercially available phase-Doppler anemometers and used this evaluation to develop the specifications required to purchase such an instrument. These specifications were then used to award a competitive bid to TSI Instruments for purchase of a PDA system. Delivery of this system is expected in the fall of 2002, in time for the UNSW and airborne measurements in 2003.

We have begun preliminary engineering required to mount the PDA on the NOAA P-3 research aircraft. This engineering has included determining electrical power requirements and the specification of an inverter capable of producing 25 A at 240VAC/60Hz single phase from 115VAC/400Hz three-phase power native to the P-3.

We have begun planning the UNSW wind-wave tunnel experiment to be conducted in January, 2003.

RESULTS

Our main result has been the purchase of a phase-Doppler anemometer from TSI Instruments. We expect delivery on this system in early November of 2002.

IMPACT/IMPLICATION

With the acquisition of the PDA, we are ready to move forward with the research goals of this project.

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PUBLICATIONS

None to date